

Search for high-mass resonances in the dilepton final state in p - p collisions at $\sqrt{s} = 13$ TeV with 2016 and 2017 data sets with the CMS detector

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Summary. — A search for new high-mass resonances decaying into electron or muon pairs has been performed using data collected at a centre-of-mass energy of 13 TeV by the CMS experiment at the CERN LHC in 2016, corresponding to an integrated luminosity of 13 fb^{-1} ; preliminary results using 2017 data, corresponding to 43 fb^{-1} , are shown. Upper limits on the product of production cross-section and branching fraction are calculated in a model-independent manner which permits the interpretation of the limits in all models predicting a narrow dielectron or dimuon resonance structure, including the Sequential Standard Model, a Superstring inspired model or the Randall-Sundrum Model with the Kaluza-Klein graviton. Limits are set on the masses of hypothetical particles that could appear in new-physics scenarios.

1. – Introduction

Neutral resonances decaying to dileptons (ee or $\mu\mu$) occur in a variety of theoretical models which attempt to extend the standard model of particle physics (SM) in order to fix its shortcomings. Examples include models described with extended gauge groups, featuring additional $U(1)$ symmetries such as the Sequential Standard Model (SSM) that includes a Z'_{SSM} boson with SM-like couplings and Grand Unified Theories (GUT) inspired models, based on the E_6 gauge group, with a Z'_ψ boson, as well as models with extra dimensions (Randall-Sundrum model with Kaluza-Klein graviton, G_{KK}).

This search channel benefits from high signal selection efficiencies and relatively small, well-understood, backgrounds.

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2. – The CMS detector

The central feature of the CMS apparatus [1] is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass and scintillator hadron calorimeter (HCAL), each composed of a barrel and two endcap sections. Forward calorimeters extend the pseudorapidity coverage provided by the barrel and endcap detectors. Muons are detected in gas-ionization chambers embedded in the steel flux-return yoke outside the solenoid.

3. – Event selection

The event selection requires particular conditions on the final-state object: at trigger level, electron candidates are selected with transverse energy (E_T) above 33 GeV while muons with transverse momentum (p_T) above 50 GeV. Then electrons are reconstructed associating tracks in the inner detector with calorimeter deposits; in the dimuon channel instead the tracks from the inner detector are associated with that of the muon system: for high- p_T (1 TeV) muons, a particular algorithm has been developed to assign the correct p_T . A dedicated high- E_T (high- p_T) selection has been developed to select electrons

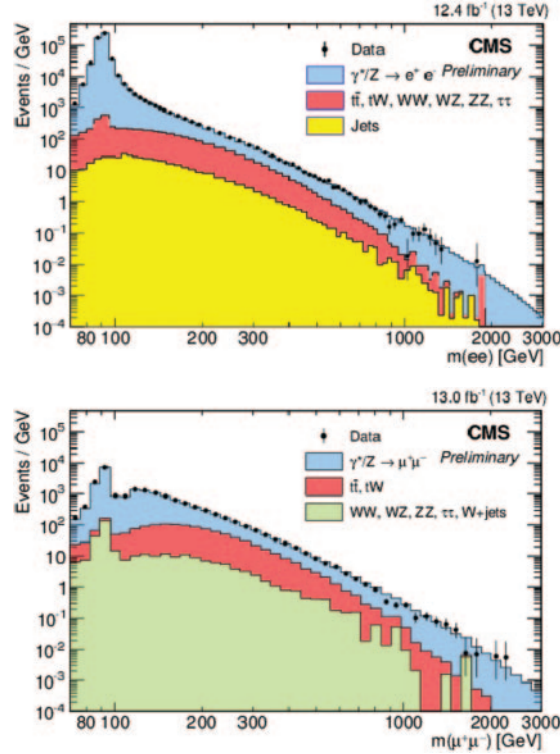


Fig. 1. – The invariant-mass spectrum, together with the predicted SM backgrounds, for the ee channel in the top panel and $\mu\mu$ channel in the bottom panel. No evidence for a signal deviation from the SM expectations is observed [2].

(muons) that must be also isolated. In the dimuon channel it is required that muons must have opposite charge (this condition is not present in the dielectron channel due to large charge misidentification for TeV electrons). For the dielectron channel, due to high multi-jets background, at least one electron must lie in the barrel region.

4. – Background

The dominant and irreducible SM background arises from Drell-Yan (DY) production (Z/γ^*) of e^+e^- and $\mu^+\mu^-$ pairs. Additional sources of background are top-antitop quark ($t\bar{t}$) and single top quark (tW), Drell-Yan $\tau^+\tau^-$ and dibosons (WW , ZZ , WZ), in which the two prompt leptons are from different particles. These processes are estimated using Monte Carlo (MC) simulated events at the next-to-leading order (NLO) and corrected to the next-to-next-to-leading order (NNLO). Events in which at least one lepton candidate is a misidentified jet (W + jets, γ + jets and multijets) contribute a small background, mainly in the electron channel, in the mass region of interest. These contributions are estimated from data. In fig. 1, the invariant-mass spectrum, together with the predicted SM backgrounds, is shown for both leptons channels. No evidence for a signal deviation

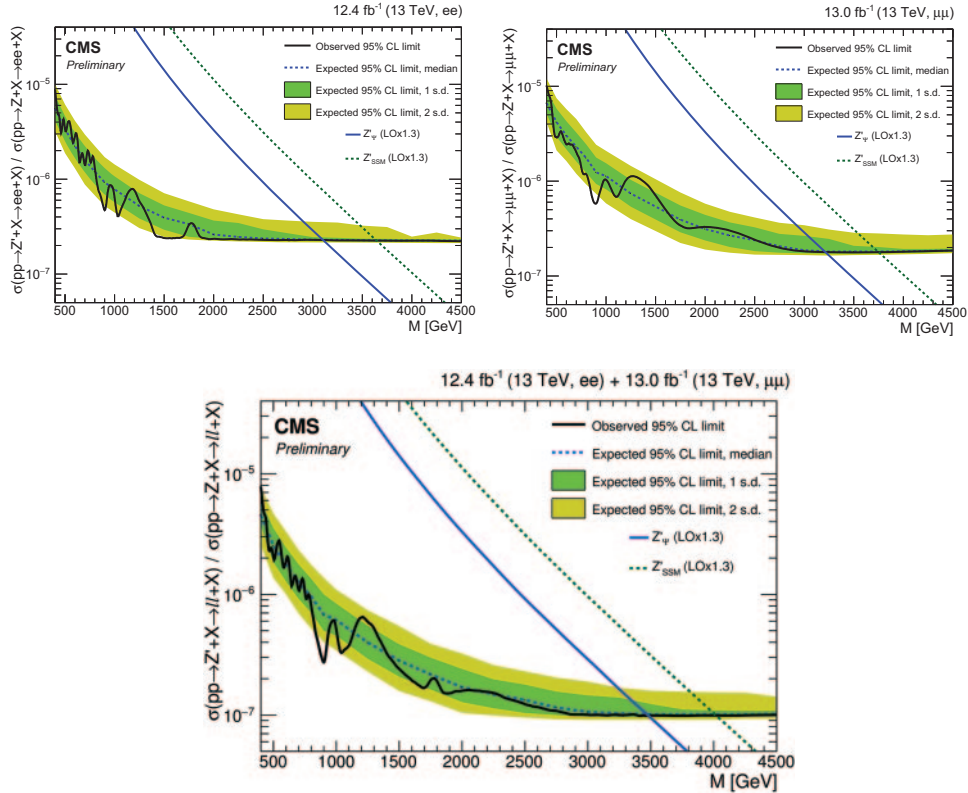


Fig. 2. – The 95% CL upper limits on the production cross-section times branching fraction for a spin-1 resonance in the ee (top left panel) and $\mu\mu$ channel (top right panel) relative to the production cross-section times branching fraction for a Z boson, using data collected during 2016 Run II (13 fb^{-1}). Bottom panel: upper limit combining the two channels [2].

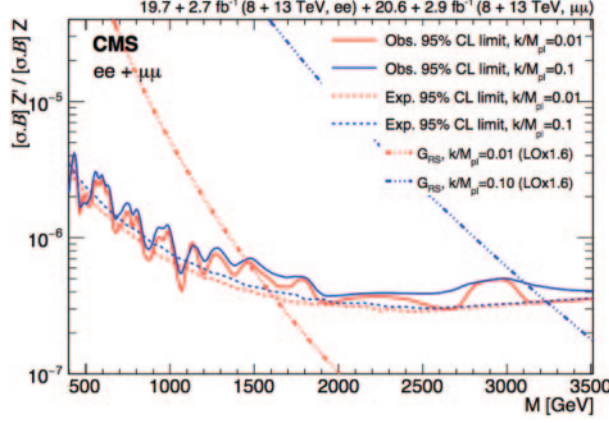


Fig. 3. – The 95% CL upper limits on the production cross section times branching fraction for a spin-2 resonance relative to the production cross section times branching fraction for a Z boson, combining dielectron and dimuon channel, using data collected during Run I (20 fb^{-1}) and during 2015 Run II (2.9 fb^{-1}) [3].

from the SM expectations is observed.

5. – Efficiency, resolution and scale

The trigger efficiency, evaluated from data (simulation), is greater than 99% in the electron (muon) channel and is uniform in E_T (p_T). Event reconstruction and selection efficiency, within the acceptance, determined from MC, corresponds to $(75 \pm 8)\%$ for 1 TeV electron pair mass, with both leptons in the Barrel (Barrel-Barrel, BB), and $(70 \pm 10)\%$ for an electron in the Barrel and the other in the Endcap (Barrel-Endcap, BE). For a 1 TeV muon pair mass it corresponds to $(91 \pm 5)\%$, and is independent of η . The acceptances rise with increasing mass. The resolutions are predicted by MC as a function of generated dilepton mass and validated with data. For 2 TeV dielectron (dimuon) pairs they correspond to $\sim 1\%$ (5.5%) for BB pairs, 1.5% (8.5%) for BE pairs. The response of the detector to leptons may evolve as the dilepton mass increases, mainly for muons. For electrons the energy scale above 500 GeV is validated at a 1–2% level. For muons the effects of misalignment, not already included in the simulation, are modelled with additional smearing applied to the dimuon mass resolution. For dimuon pairs, an additional 1% uncertainty is assigned in the position of the mass peak to account for other possible sources of scale bias such as detector movement due to magnet cycles.

6. – Analysis strategy and results

Using a Bayesian approach with an unbinned extended likelihood function, limits are derived for the production of a narrow spin 1 (Z'_{SSM} , Z'_ψ) –see fig. 2 –and spin 2 (G_{KK}) heavy resonance –see fig. 3. The likelihood function is based on probability density functions that describe the signal and the background contributions to the invariant-mass spectra:

- Signal: parametrized by the convolution of a Breit-Wigner (describing the intrinsic signal shape) and a Gaussian distribution (describing the experimental resolution).

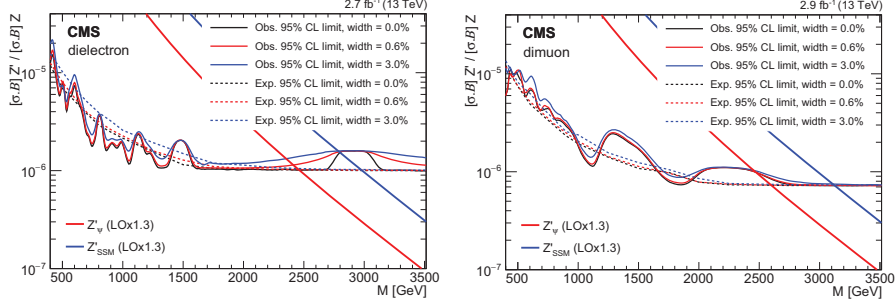


Fig. 4. – The 95% CL upper limits, in different width configurations, on the production cross-section times branching fraction for a spin-1 resonance relative to the production cross-section times branching fraction for a Z boson, in dielectron (left) and dimuon (right) channel, using data collected during 2015 Run II (2.9 fb^{-1}) [3].

- Background: parametrization obtained by fitting the SM simulated background distribution.

The limits are set on the parameter R_σ which is the ratio of the cross-section for dilepton production through a Z' boson to the cross-section for dilepton production through a Z boson. This strategy led to cancel out of a number of experimental and theoretical uncertainties: only uncertainties with a mass dependence need to be taken into account. The Poisson mean of the signal yield is $\mu_s = R_\sigma \mu_Z R_\epsilon$, where R_ϵ is the ratio of the selection efficiency times detector acceptance for the Z' decay relative to that for the Z boson and μ_Z is the Poisson mean of the number of $Z \rightarrow ll$ events. To obtain the limit for a dilepton mass point, the amplitude of the background shape function is constrained using data within a mass window ± 6 times the mass resolution about the mass point.

In order to be sure that the analysis is model independent, the upper limits have been evaluated considering different widths for the resonance: 0, 0.6 and 3% of the mass (fig. 4).

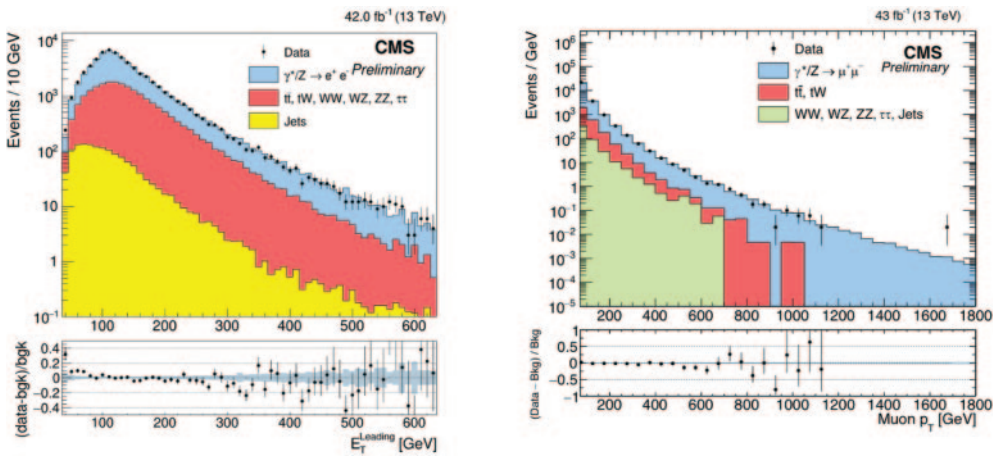


Fig. 5. – Electron transverse energy E_T (on the left) and muon transverse momentum p_T (on the right) distribution using the 2017 data set.

For mass below 1 TeV, the expected limits become less stringent as the resonance mass increases while at high masses, the limits do not exhibit any dependence on the assumed resonance width. The observed limits are robust and do not significantly change for reasonable variations in the limit-setting procedure (mass intervals, background shape).

For the Z'_{SSM} particle and for the superstring inspired Z'_ψ particle, 95% confidence level lower mass limits are found to be 4.0 TeV and 3.5 TeV (using 2016 data) [2]. The corresponding limits for Kaluza-Klein gravitons (G_{KK}) arising in the Randall-Sundrum model of extra dimensions with coupling parameters 0.01 and 0.1 are 1.46 and 3.11 TeV, respectively (combining 8 TeV data with 2015 Run II) [3].

7. – 2017 Performance plot

During 2017 CMS has collected 43fb^{-1} : in fig. 5 the first results using 2017 data showing good agreement between observation and simulation are reported.

REFERENCES

- [1] THE CMS COLLABORATION, *JINST*, **3** (2008) S08004.
- [2] THE CMS COLLABORATION, *Search for a high-mass resonance decaying into a dilepton final state in 13 fb^{-1} of pp collisions at $\sqrt{s} = 13\text{ TeV}$* , <http://cds.cern.ch/record/2205764>.
- [3] THE CMS COLLABORATION, *Phys. Lett. B*, **768** (2017) 57.